QU'APPELLE FISHING LAKES

NUTRIENT LOADING STUDY, 1980 TO 1983

FINAL REPORT

DECEMBER 1986

D. J. MUNRO
ENVIRONMENT CANADA
WATER QUALITY BRANCH
REGINA, SASKATCHEWAN

NQB - WMR - 86 - 02

QU'APPELLE FISHING LAKES
NUTRIENT LOADING STUDY, 1980 TO 1983

FINAL REPORT

DECEMBER, 1986

D.J. MUNRO

ENVIRONMENT CANADA

WATER QUALITY BRANCH

WESTERN AND NORTHERN REGION

REGINA, SASKATCHEWAN

WQB - WNR - 86 - 02

ABSTRACT

Intensive sampling for nitrogen and phosphorus was undertaken in the Qu'Appelle River from April, 1980 to June, 1983 by Environment Canada, Water Quality Branch. This work was intended to fulfill a recommendation made by the Qu'Appelle Valley Management Board and federal and provincal government agencies, that trends in nutrient loading to and from the Fishing Lakes be determined. At the upstream site 72 hour composite samples were collected, while below the Fishing Lakes a grab sample was collected every 72 hours. The nutrient data and Water Survey of Canada flow data were used to calculate nutrient loads. A net phosphorus export from the lakes of 43.19 tonnes occurred during the study and 829.1 tonnes of nitrogen was retained in the lakes. A significant change in the phosphorus forms occurred between the two sites: upstream the majority of the phosphorus was particulate, while downstream most was dissolved ortho-phosphorus. The shift in phosphorus form and the net export of phosphorus from the lake suggest that phosphorus is being regenerated from the bottom sediment. The retention of nitrogen within the lakes results in a very low nitrogen to phosphorus ratio in the lakes, suggesting that nitrogen may be limiting algal growth.

RÉSUMÉ

La Direction de la qualité des eaux d'Environnement Canada a procédé à des travaux intensifs d'échantillonnage de l'azote et du phospore dans la Qu'Appelle entre avril 1980 et juin 1983. Ces travaux avaient pour objet de donner suite à une recommandation, présentée par la Commission administrative de la vallée de la Qu'Appelle et des organismes des gouvernements fédéral et provinical, visant à déterminer les tendances concernant la teneur en substances nutritives qui arrivent dans les lacs Fishing ou qui en sortent. Des échantillons moyens étaient constitués sur une période du 72 heures au point de prélèvement en amont tandis qu'en aval des lacs Fishing, on prélevait un échantillon instantané aux 72 heures. Les données sur les substances nutritives et les données d'écoulement de la Division des relevés hydrologiques du Canada ont servi à calculer la teneur en substances nutritives. Au cours de l'étude, l'exportation nette de phosphore en provenance des lacs s'ete établie à 43,19 tonnes et la quantité d'azote gardée dans les lacs a été de 829,1 tonnes. On a noté un changement important de la forme du phosphore entre les deux points d'échantillonnage: ainsi, au point en amont, la plus grande partie du phosphore était sous forme de particules tandis qu'au point en aval, il se retrouvait surtout sous forme d'orthophosphates dissouts. Ce phénomène de transformation, ainsi que l'exportation nette de phosphore par les lacs, donnent à penser que le phosphore y est regénéré sous l'action des sédiments du fond. Par contre, la rétention d'azote dans les lacs fait qu'il y a un très faible rapport azote-phospore, ce qui permet de penser que l'azote limite peut-etre le développement d'algues.

TABLE OF CONTENTS

		PAGE
ABSTRACT		i
RESUME		i
TABLE OF CONTENTS		ii
LIST OF TABLES		iii
LIST OF FIGURES		iii
1.0	SUMMARY AND CONCLUSIONS	1
2.0	RECOMMENDATIONS	2
3.0	INTRODUCTION	3
3.1	Study Area	5
4.0	METHODS	8
4.1	Sampling Locations	8
4.2	Sample Collection	8
4.2.1	Composite Samples	8
4.2.2	Cross Sectional Samples	9
4.2.3	Quality Control Samples	11
4.2.4	Phosphorus Speciation Samples	11
4.3	Sample Handling and Analyses	11
4.4	Flow	11
4.5	Data Computations	12
4.5.1	Loading	12
5.0	RESULTS	14
5.1	Flow	14
5.2	Variability in Nutrient Concentrations	14
5.2.1	Phosphorus	14
5.2.2	Nitrogen	19
5.3	Nutrient Loading	20
5.3.1	Phosphorus Loading	20
5.3.2	Nitrogen Loading	24
5.4	Phosphorus Speciation	24
6.0	DISCUSSION	28
6.1	Phosphorus	28
6.2	Nitrogen	30
6.3	Assessment of Sampling Frequency	32
ACKNOWLEDGEMENTS		35
REFERENCES		36

LIST OF TABLES

NUMBER		PAGE
1	Statistical Summary of the Correction Factors Used in the Nutrient Load Calculations.	10
2	Total Annual Nutrient Load To and From the Fishing Lakes (Tonnes).	23
3	Phosphorus Species in the Qu'Appelle River.	27
4	Phosphorus Load Calculations Based on Various Sampling Periods for the Qu'Appelle River above Pasqua Lake.	33
5	Phosphorus Load Calculations Based on Various Sampling Periods for the Qu'Appelle River below Katepwa Lake.	34

LIST OF FIGURES

NUMBER		PAGE
1	Qu'Appelle River Basin Showing Sample Collection Locations.	6
2	Mean Discharge and Phosphorus Concentration in the Qu'Appelle River Above Pasqua Lake.	15
3	Mean Discharge and Phosphorus Concentration in Qu'Appelle River Below Katepwa Lake.	16
4	Mean Discharge and Nitrogen Concentration in the Qu'Appelle River Above Pasqua Lake.	17
5	Mean Discharge and Nitrogen Concentration in the Qu'Appelle River Below Katepwa Lake.	18
6	Monthly Phosphorus Load in the Qu'Appelle River Above Pasqua Lake.	21
7	Monthly Phosphorus Load in the Qu'Appelle River Below Katepwa Lake.	22
8	Monthly Nitrogen Load in the Qu'Appelle River Above Pasqua Lake.	25
9	Monthly Nitrogen Load in the Qu'Appelle River Below Katepwa Lake.	26

1.0 SUMMARY AND CONCLUSIONS

Intensive sampling for nitrogen and phosphorus was undertaken in the Qu'Appelle River at sites above Pasqua Lake and below Katepwa Lake from April, 1980 to June, 1983, by the Water Quality Branch. The analytical results from this sampling program were used in conjunction with Water Survey of Canada flow data to determine nutrient loads into and out of the Qu'Appelle Fishing Lakes and to examine the associated nutrient forms.

Based on the results of these samples, it was calculated that there was a net export of over 43.19 tonnes of phosphorus from the lakes and 829.1 tonnes of nitrogen was retained within the lakes. These loads are based on an inflow and outflow of 135.10 and 178.29 tonnes of phosphorus and 1244.4 and 467.2 tonnes of nitrogen, respectively.

Examination of the phosphorus data shows that a significant change in the relative proportion of the phosphorus forms present occurs within the Fishing Lakes. In the inflow, the majority of the phosphorus is particulate phosphorus (64 percent), most of which is believed to be deposited in the Pasqua Lake sediments along with the suspended solids. In the outflow from the lakes, the majority of the phosphorus is dissolved (86 percent) and a large portion of that is highly available ortho-phosphorus. The substantially higher concentration of dissolved phosphorus in the outflow than in the inflow is presumptive evidence that in-lake processes, including regeneration of phosphorus from the lake sediments, are major factors affecting the quality of the lakes. The lake sediments represent a significant pool of phosphorus for the lakes. Although the major controllable pollution sources have now been effectively controlled, thereby significally reducing anthropogenic phosphorus sources to the Qu'Appelle River Basin, the need exists to establish the role lake sediments may play in perpetuating nutrient related water quality problems.

Nitrogen concentrations are substantially lower in the outflow from the Fishing Lakes than in the inflow. This results in a substantial difference in the total nitrogen to total phosphorus ratios between the inflow (9.2 to 1) and the outflow (2.6 to 1). The ratio of nitrogen to phosphorus leaving the lakes is so low that it lends credence to the theory put forth by others that it is nitrogen, and not phosphorus, that is currently the nutrient limiting algal growth in the Fishing Lakes.

The intensive sampling results from this study were used to estimate the frequency of sampling which would be required to obtain acceptable estimates of the phosphorus load into the Fishing Lakes. These estimates show that to obtain phosphorus load with a ten percent error, weekly sampling would be required for seasonal loads at the upstream site and biweekly sampling

would suffice at the downstream site. Annual loads with the same error could be determined from biweekly and monthly sampling at the upstream and downstream sites, repectively.

2.0 RECOMMENDATIONS

1) Study of the inlake processes which occur in the Fishing Lakes should be considered in order to determine the significance of internal regeneration of phosphorus within the lakes and the fate of particulate phosphorus entering the lakes from the Qu'Appelle River.

2) Assessment of other sources of nutrients to the Fishing Lakes, including local runoff, ground water and precipitation, is needed in order to better understand the nutrient balance of the lakes.

3) Continued monitoring in the Qu'Appelle River above the Fishing Lakes and at the outlet of Katepwa Lake is required in order to obtain more data under various flow conditions to effectively assess the nutrient quality of the Qu'Appelle River and the effect of nutrient management activities. It is not necessary to monitor as frequently as in this study, but the samples must be collected year round and at a frequency which will produce a load estimate which is of acceptable accuracy for the management of the system.

3.0 INTRODUCTION

The Fishing Lakes on the Qu'Appelle River are a major recreational resource for the people of southern Saskatchewan. The Qu'Appelle Basin Study (1972) conducted in the early 1970's identified excessive algal and plant growths as the major water related problems which interfered with the recreational use of these lakes. This highly eutrophic condition was asserted to be the result of large nutrient loads to the Basin.

Induced, or 'cultural' eutrophication, is generally caused by excessive input of plant nutrients (eg. phosphorus) and sediment from sewage disposal, livestock operations, fertilizer runoff from agricultural land, breaking of natural land for cultivation causing increased erosion, and other activities. This increased input of nutrients can greatly stimulate algal and other aquatic plant growth, resulting in undesirable changes in the chemical, physical and biological characteristics of the water body. Cultural eutrophication is controllable and reversible to a large extent, although such efforts may require extensive control programs.

The natural eutrophication of the Qu'Appelle Fishing Lakes was probably well advanced before European settlement of the prairies. Evidence of this is found in reports from early explorers who found extensive algal blooms on the lakes during the summer and from the high levels of phosphorus found in sediment cores from depths representing presettlement deposition (Allan, et al., 1980.). Man's activities, however, have greatly increased the rate of eutrophication in the lakes. Initially the breaking of the land for farming increased the sedimentation rates and the input of nutrients due to the increased erosion of the exposed nutrient rich soil. As the population grew and cities developed, sewage disposal further increased the nutrient load to the Qu'Appelle River Basin. The Qu'Appelle Basin Study (1972) reported that nearly 70 percent of the phosphorus and nitrogen in the Qu'Appelle River system originated from municipal sewage systems.

To reduce the eutrophication rate, the Qu'Appelle Basin Study Board (1972) recommended that the cities of Regina and Moose Jaw reduce their phosphorus input to the Qu'Appelle River Basin and that major livestock operations modify their practices. Recommendations were also made for further water quality monitoring and research to clarify the problems and to determine solutions.

In 1975, the Qu'Appelle Agreement was signed by the Canadian and Saskatchewan Governments. The objectives of the agreements were as follows:

(a) to ensure the long term productivity of the Qu'Appelle Valley's recreation and tourism resource base, including the natural environment, historic resources, cultural

heritage and hospitality industry;

(b) to increase the benefits from utilization of this resource base in terms of:

- improved incomes and greater diversity of employment opportunities for residents of the Qu'Appelle Valley, and

- increased recreational opportunities for residents of the nearby urban centres, particularly Regina and Moose Jaw, thereby influencing individual locational decisions of employers and members of the labour force in favour of these centres; and

(c) to improve the management of the land and water resources of the Qu'Appelle Valley to meet existing and future uses of these resources.

As part of the Qu'Appelle Agreement, approximately 5.6 million dollars has been spent primarily to reduce the phosphorus input to the Qu'Appelle River system (Reid Crowther/DPA Consortium, 1984) and thereby reduce the eutrophication rate of the lakes, or at least prevent the eutrophication from worsening. Recent advances in the knowledge of factors affecting water quality have led some researchers to question if such controls alone will result in improvements in the highly eutrophic state of the Fishing Lakes (Allan,1980).

In 1979, it was recognized by the Qu'Appelle Valley Management Board, henceforth referred to as the 'Board', as well as Federal and Provincial agencies, that the ongoing water quality monitoring activities were insufficent to assist the Board in determining the effectiveness of the pollution abatement measures undertaken. As a result, the concerned agencies jointly recommended (Reid, 1979):

(1) an evaluation be carried out of existing data for Wascana Creek and Qu'Appelle River below Wascana Creek;

(2) trends in nutrient loadings to and from the Fishing Lakes be determined;

(3) lake productivity surveys be conducted; and

(4) regular ongoing monitoring by government agencies be continued.

Environment Canada, Water Quality Branch (Branch) agreed to address the second activity, proposing a long term five-year study with the following specific objectives:

(1) to conduct intensive sampling of the Qu'Appelle River to accurately determine nutrient loading into and out of the Fishing Lakes;

(2) to estimate the effect of the City of Regina's tertiary treatment plant on the phosphorus loading to the Fishing Lakes. Effluent from the City of Moose Jaw would also be reviewed in this same context; and

(3) to estimate trends in the nutrient quality, loading and productivity of the Qu'Appelle River above Pasqua Lake and below the Fishing Lakes.

This report addresses the first objective of the Branch's study by presenting the results of 39 months (April 1980 to July 1983) of intensive sampling at two sites on the Qu'Appelle River. The report includes computational estimates of the nutrient loads into and out of the Fishing Lakes during this time. In addition to this report, three interim reports have been prepared based on these data (Water Quality Branch 1982a, 1982b and 1983). The other two objectives have been addressed in other reports (Munro, 1985; 1986), which examines phosphorus loads in the Qu'Appelle River above the Fishing Lakes and periphyton productivity in the Qu'Appelle River.

Traditional examination of phosphorus water quality has focused primarily on total phosphorus concentrations. However, to accurately estimate trophic state, it is necessary to consider the abundance of biologically available phosphorus. Ortho-phosphate, or soluble reactive phosphorus, has been widely used to estimate biologically available phosphorus. Other forms of phosphorus have also been shown to be available. Therefore, this study also examined the chemical speciation of the phosphorus present in the Qu'Appelle River in order to estimate the quantity of biologically available phosphorus in the system.

Nitrogen was also included in this study, as evidence has been presented that suggests nitrogen rather than phosphorus may be a limiting factor for algal growth in the Fishing Lakes (Allan and Kenny, 1978). Therefore, accurate characterization of nitrogen concentrations and loads should be of assistance in future planning of pollution control measures.

The Branch began its proposed five year study in the spring of 1980 (funded by Canada and Saskatchewan). The study terminated prematurely in June 1983 when required resources were no longer forthcoming for continued monitoring.

3.1 STUDY AREA

The Qu'Appelle River Basin extends approximately 400 km, from its headwaters near Lake Diefenbaker to its confluence with the Assiniboine River, and drains an area of approximately 52 000 square kilometres (Qu'Appelle Basin Study Board, 1972). Th Qu'Appelle River is a mature river having a broad flood plain and well developed meanders. The river flows through seven lakes (Figure 1), these being Buffalo Pound Lake, the Fishing Lakes (Pasqua, Echo, Mission and Katepwa), Crooked Lake and

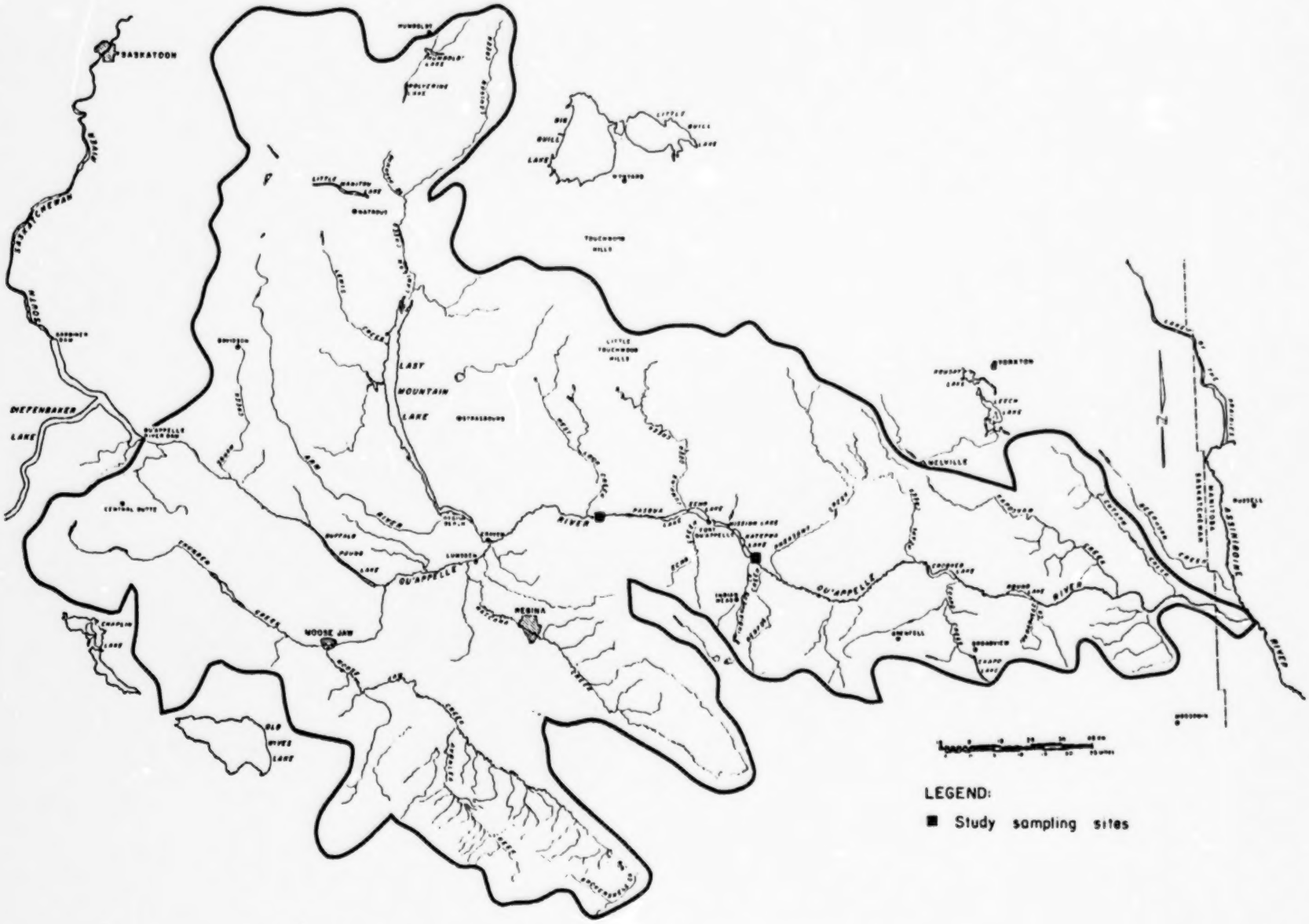

Figure 1. Qu'Appelle River Basin Showing Sample Collection Locations.

Round Lake. Last Mountain Lake discharges into the Qu'Appelle River through Last Mountain Creek. During periods of high flow, however, water from the Qu'Appelle River may flow unregulated into Last Mountain Lake. During periods of low flow, a control structure near Craven can be used to divert Qu'Appelle River water into Last Mountain Lake. Water may also enter the Qu'Appelle River system from the South Saskatchewan River by a diversion channel connecting Lake Diefenbaker to Buffalo Pound Lake.

There are numerous minor tributaries to the Qu'Appelle River and about ten major tributaries, of which Moose Jaw River and Wascana Creek are the most significant. The tributaries generally have their highest flows during spring runoff, with little or no flow during the remainder of the year. During these low or no flow periods, river reaches often become plugged with aquatic weed growth.

The Qu'Appelle River Basin provides water for municipal and industrial use, agriculture (irrigation and livestock watering), recreation, and wildlife habitat. The major portion of the basin is agricultural land, in particular cereal cropping. However, a substantial number of livestock operations exist throughout the basin, mainly along the river valley and the tributaries. The large population centres, Regina and Moose Jaw, are the major users of the Qu'Appelle River water. Both cities draw their municipal water supply from Buffalo Pound Lake and discharge their sewage effluents to Wascana Creek and Moose Jaw River, repectively.

The soils in 75 percent of the upper Qu'Appelle River Basin are dark brown Chernozemic soils, with a soil capability classification from Class 2 to Class 5. These soils are developed on lacustrine, alluvial lacustrine, alluvial glaciofluvial and glacial till parent materials. The main drainage channels and their flood plains occupy about ten percent of the upper basin and are azonal soils characteristic of the alluvium and tillwash complexes (ARDA, 1968).

The climatic condition in the Qu'Appelle River Basin is characterized by hot summers, cold winters and moderate precipitation. Mean annual precipitation ranges from 350 to 420 mm within the basin, of which 25 percent occurs as snow (Qu'Appelle Basin Study Board, 1972). Variation in precipitation alters the effective drainage area of the Qu'Appelle River dramatically due to the relatively flat land. The effective drainage area in a dry year may only be 50 percent that of a wet year (Tones, 1981).

4.0 METHODS

4.1 Sampling Locations

Automatic composite samplers, collocated with Water Survey of Canada (WSC) hydrometric stations, were installed at two locations (Figure 1). The location above the Fishing Lakes, Qu'Appelle River above Pasqua Lake, WSC Station Number 05JK007 (site A on Figure 1), is 21.1 km upstream of Pasqua Lake (Prairie Farm Rehabiliation Administration, 1980). The location below the Fishing Lakes, Qu'Appelle River below Katepwa Lake, WSC Station Number 05JL001 (site B on Figure 1), is approximately 0.5 km downstream of the outlet structure on Katepwa Lake. The hydrometric station at the outlet of Katepwa Lake had to be re-established for this study after modifications to the outlet structures necessitated the closing of the original gauging station.

4.2 Sample Collection

In order to accurately estimate nutrient loading at the two study sites, it is necessary to collect samples at a frequency suited to the variability of the water quality variables and of the hydrograph; samples must also be representative of the cross section from which the samples are collected; and the error associated with the methods (including sample treatment steps) must be known. In order to obtain the above required information a number of types of samples were collected.

4.2.1 Composite Samples

Composite samples were collected using a refrigerated automatic sampler developed by Saskatchewan Research Council (Model Mark IIIB). The samplers collected approximately 100 mL of river water from midstream every two hours. The 100 mL aliquots were composited over a 72 hour period. When, on account of equipment malfunction or low flows, a composite sample was not collected, a discrete grab sample from midstream was substituted. These composite and grab samples were used to determine temporal variability in nutrient concentrations and to compute loadings.

The operation of the automatic samplers was unreliable during the early stages of the study due to numerous malfunctions related to equipment design. Problems were encountered with the pumps and the solenoid switch. As a result, numerous different pumps were used until a suitable one was found and put into use in early October, 1980. The solenoid switch problems were caused by suspended sediment plugging the switching mechanism. Modification of the switching mechanism relieved the problem temporarily and another design of switching mechanism was installed in January, 1981. During 1980, low flow conditions at the sampling site below Katepwa Lake periodically

resulted in insufficient water depth to accommodate an inlet orifice, thereby preventing the use of the automatic sampler. Due to continuing low flow conditions in 1981, the use of a composite sampler was discontinued at this site after March 19, 1981. Grab samples were collected for the remainder of the study.

As a result of the need to substitute a substantial number of grab samples for composite samples in the first year of the study, it was deemed necessary to compare the two sample collection methods. The results of the comparison (Water Quality Branch, unpublished data) showed that statistically significant differences in nutrient concentrations between composite and grab samples occurred only for total nitrogen and only at the site below Katepwa Lake. The composite samples had higher total nitrogen than the grab samples; the mean difference between 27 pairs of data was 0.1 mg/L, about 6.6 percent of the mean concentration in the composite samples. All paired samples were collected during periods of relatively low flow during 1980. Based on this information, it was concluded that grab samples could be substituted for composite samples during low flow periods without greatly affecting the accuracy of the load calculations. Assuming that composite samples provide the best estimate, the total nitrogen load calculation at the site below Katepwa Lake would tend to be slightly lower by subtituting grab samples.

In April, 1983 the sampling frequency was reduced to 84 hours instead of 72 hours. This change was instituted in order to better facilitate logistic support.

4.2.2 Cross Sectional Samples

To assess cross sectional heterogeneity, it was necessary to determine the relationship between the composite samples (point sampler) and samples collected at random from the cross section. In order to accomplish this, the cross section was sampled on 22 occasions below Katepwa Lake and on 26 occasions above Pasqua Lake. On each occasion, 10 discrete grab samples were collected from points randomly selected from a half metre square grid of the cross section. Concurrent with the collection of the cross sectional grab samples, three samples were obtained by manually initiating the automatic sampler. The comparison of the cross section samples and the manually initiated composite samples were then used to determine a river cross section correction factor (K) which was applied in the equation for computing loads. The mean correction factors for the nutrients examined at the two sites were less than three percent (Table 1). At the site below Katepwa Lake after automatic sampling was discontinued, three discrete grab samples taken from midstream were substituted for the manually initiated automatic samples.

Table 1. Statistical Summary of Correction Factors Used in the Nutrient Load Calculations.

Parameter/ Correction Factor	Median	Mean	Standard Deviation	Minimum	Maximum	Number
Qu'Appelle River Above Pasqua Lake						
Total Phosphorus						
K	0.988	0.971	0.091	0.714	1.11	21
k	0.052	0.062	0.049	0.0	0.20	21
c	0.005	0.006	0.005	0.0	0.02	20
Dissolved Phosphorus						
K	1.00	0.996	0.137	0.655	1.43	22
k	0.099	0.136	0.154	0.025	0.748	22
c	0.004	0.004	0.003	0.011	0.011	20
Total Nitrogen						
K	1.00	0.996	0.083	0.823	1.18	22
k	0.067	0.108	0.115	0.019	0.468	22
c	0.087	0.168	0.235	0.0	1.00	20
Dissolved Nitrogen						
K	1.01	1.02	0.059	0.867	1.12	22
k	0.050	0.067	0.060	0.021	0.308	22
c	0.039	0.131	0.217	0.0	0.837	20
Qu'Appelle River Below Katepwa Lake						
Total Phosphorus						
K	0.996	0.988	0.048	0.878	1.07	22
k	0.032	0.047	0.045	0.0	0.193	22
c	0.005	0.008	0.008	0.0	0.037	19
Dissolved Phosphorus						
K	1.00	0.996	0.026	0.923	1.03	22
k	0.028	0.034	0.023	0.005	0.107	22
c	0.005	0.006	0.005	0.0	0.028	19
Total Nitrogen						
K	1.00	0.966	0.105	0.565	1.10	22
k	0.060	0.065	0.048	0.0	0.241	22
c	0.045	0.067	0.010	0.0	0.447	19
Dissolved Nitrogen						
K	1.00	0.991	0.040	0.873	1.05	22
k	0.037	0.042	0.022	0.019	0.112	22
c	0.023	0.034	0.034	0.0	0.114	19

K = the correction factor calculated in equation 2
k = the uncertainty of K calculated in equation 4
c = standard deviation of the mean of 5 aliquots (section 4.2.3)

4.2.3 Quality Control Samples

Quality control samples were collected on 19 occasions at the site below Katepwa Lake and on 20 occasions above Pasqua Lake to examine the variability in the sample splitting procedures and analytical methods. Each quality control sample consisted of collecting three discrete grab samples from midstream. Each sample was subsequently split into five subsamples which were submitted for indentical analyses. Any variation in the analytical results were assumed to be a function of the analytical and/or sample handling procedure and were used to determine the uncertainty of the nutrient concentrations (c) used in calculating the uncertainty of the nutrient loads.

4.2.4 Phosphorus Speciation Samples

Phosphorus speciation samples were collected on 14 occasions at each site at the same time as quality control samples were collected. These samples were used to examine the forms of phosphorus present in the water and to give an indication of the bioavailable phosphorus. Five replicate sets of samples for ortho-phosphorus, total inorganic phosphorus and dissolved inorganic phosphorus analyses were collected from the quality control sample used for analyses of total phosphorus and total dissolved phosphorus.

4.3 Sample Handling and Analyses

All samples were placed in four litre polyethylene containers. Composite samples were refrigrated throughout the 72 hour collection period. Samples were cooled on ice packs during transport to the Regina field laboratory. All samples were processed on the same day they were received at the field laboratory. Processing involved using a modified four litre erlenmeyer flask with a draw-off near the bottom of the flask. The complete sample was mixed using a magnetic stirrer to ensure homogeneity and aliquots were drawn off into the appropriate containers. Subsamples for dissolved nutrient analyses were taken from the flask using a peristaltic pump and then filtered through 0.45 um cellulose acetate filter paper.

The analyses were conducted at the Water Quality Branch, Calgary, Laboratory and were analyzed according to the analytical methods manual (Water Quality Branch, 1979).

4.4 Flow

Flow into and out of the Fishing Lakes was determined by Water Survey of Canada as part of their routine monitoring network.

At the site above Pasqua Lake (Qu'Appelle River below Loon Creek) the stage is recorded continuously by a Stevens type A recorder mounted on a round timber well (House, 1981a). At the site below the lakes (Qu'Appelle River below Katepwa Lake) the hydrometric station had to be re-established because modifications to the outlet structures on Katepwa Lake necessitated the closing of the earlier gauging station (Qu'Appelle River at the outlet of Katepwa Lake). The stage at the new site is continuously recorded by a servo-manometer activated Stevens recorder. The recorder is set to a wire weight gauge mounted on the highway bridge about 75 metres upstream of the gauge (House, 1981b).

4.5 Data Computation

4.5.1 Loading

Load calculations for the two study sites were made using the flow data provided by Water Survey of Canada and the concentrations determined from the three day composites or grab samples collected at each site. The equations used are as follows:

The total load for the time period in tonnes is:

$$L = U \sum_{i=1}^{N} Q_i C_i K_i \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(Eq. 1)}$$

where:

- U = a constant conversion factor to provide appropriate units
- i = the i^{th} compositing interval
- N = number of compositing intervals for the time period
- Q = the mean discharge during the compositing interval in cubic metres per second
- C = the nutrient concentration of the sample in milligrams per liter
- K = a dimensionless correction factor for any systematic error introduced by sampling a single point in a heterogeneous cross section (Eq. 2).

As mentioned earlier, K is estimated by comparing the mean of 10 samples ($\bar{X}_{10}$) collected at random from the cross section to the mean of three samples ($\bar{X}_3$) collected at 20 minute intervals from the automatic sampler.

$$K = \frac{\bar{X}_{10}}{\bar{X}_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(Eq. 2)}$$

Correction factors were calculated for each set of cross sectional samples. Correction factors were then estimated for each sampling date by dividing the time period between the cross-sectional sampling dates at the mid point, then applying the calculated correction factors to the data collected in the periods adjacent to each cross-sectional sampling date as if it had been determined on that date.

The uncertainty of the loading computation is determined by the following computation (Shoemaker, et al., 1974) which assumes normal and independently distributed errors.

$$l = U\sqrt{\sum_{i=1}^{N} Q_i^2 C_i^2 K_i^2 \left(\left(\frac{q_i}{Q_i}\right)^2 + \left(\frac{c_i}{C_i}\right)^2 + \left(\frac{k_i}{K_i}\right)^2\right)} \quad \text{(Eq. 3)}$$

where q, c, k, are the uncertainties in Q, C, K, respectively and U is the constant unit converter.

Q and q were provided by Water Survey of Canada. C is a single analytical determination on the composite sample. c is the standard deviation of the mean of five aliquots obtained by homogeneously splitting quality control samples (Section 4.2.3). The uncertainty of C was determined for each set of quality control samples collected during the study period and estimated for each sampling date by the interpolation technique described above for K.

The uncertainty in K (Shoemaker, et al., 1974) expressed as k is:

$$k = K\sqrt{\left(\frac{S_{10}}{\bar{X}_{10}}\right)^2 + \left(\frac{S_3}{\bar{X}_3}\right)^2} \quad \text{(Eq. 4)}$$

where:

S_{10} = the standard deviation of the 10 randomly collected samples from the cross section and

S_3 = the standard deviation of the three manually initiated composite samples.

5.0 RESULTS

5.1 Flow

During the period of intensive sampling there was a wide variation in the hydrograph of the Qu'Appelle River. Annual flow conditions varied throughout the study period, low and moderate flow conditions occurred during 1980 and 1981, 1982 and 1983 were moderately high flow years. The annual discharge in the Qu'Appelle River below Craven from 1980 to 1983 was 56 400, 57 200, 226 000, and 201 000 dam^3, respectively and the discharge during the first six months of 1983 was 119 500 dam^3. Mean annual discharge for the period of record at this location is 158 000 dam^3, with a range from 9 210 to 653 000 dam^3 (1955-1982). At the collection site above Pasqua Lake the annual discharge, 1980 to 1983, were similiar to those below Craven Dam (65 100, 54 700, 205 000 and 201 000 dam^3, respectively). At the site below Katepwa Lake the annual discharge during these periods were 59 900 (March to December), 47 600, 213 000 and 236 000 dam^3, which are comparable to those for the location above Pasqua Lake. The difference between the sites immediately above and below the Fishing Lakes can be attributed to change in storage in the lakes, local runoff, ground water inputs and evaporation which occurred between the two sites. All flow data used were collected by Water Survey of Canada (1980, 1981, 1982, 1983).

The flow for the sites above and below the Fishing Lakes during the period of intensive sampling is shown in Figures 2 to 5. These flow data are based on mean flows coinciding with the nutrient sample collection periods and were calculated from Water Survey of Canada mean daily flow results.

5.2 Variability in Nutrient Concentration

5.2.1 Phosphorus

A total of 388 composite or grab samples were collected between April 5, 1980 to June 27, 1983 at the site on the Qu'Appelle River above Pasqua Lake. At the site below Katepwa Lake one less sample was collected due to the three day later start up of the the automatic sampler at this loacation. The temporal variability in phosphorus concentration over the sampling periods for the two sites is shown in Figures 2 and 3. The flow data which coincide with the nutrient data are also shown in these Figures.

Figure 2 shows that during the first two years of this study there was considerable variation in the phosphorus concentration at the site above Pasqua Lake. Concentration generally ranged from 0.2 to 1.0 mg/L. On three occasions in 1980 the phosphorus concentration was significantly higher than this range (maximum 2.9 mg/L). On each of these occasions there was a corresponding increase in turbidity and non-filterable

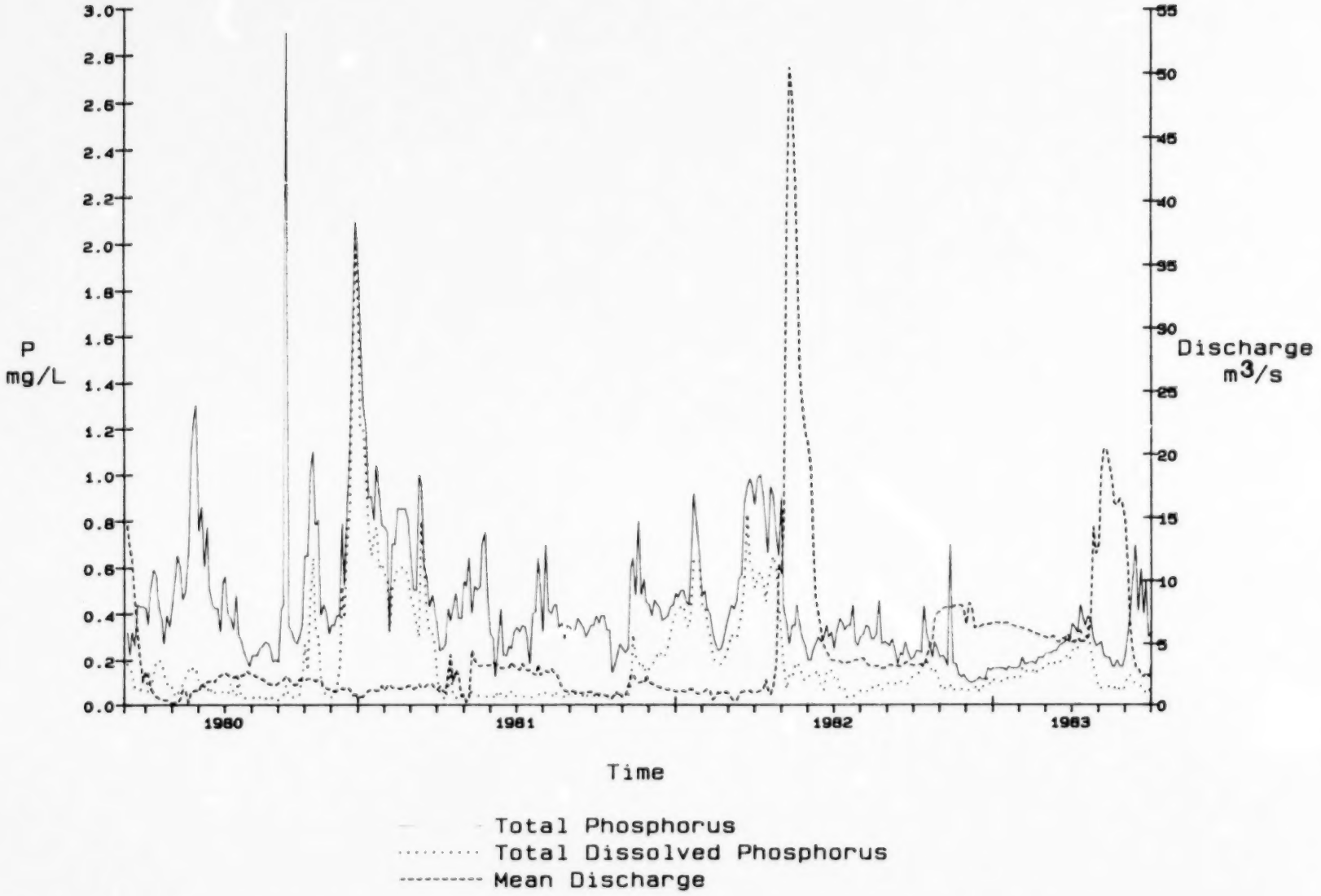

Figure 2. Mean Discharge and Phosphorus Concentration in the Qu'Appelle River Above Pasqua Lake.

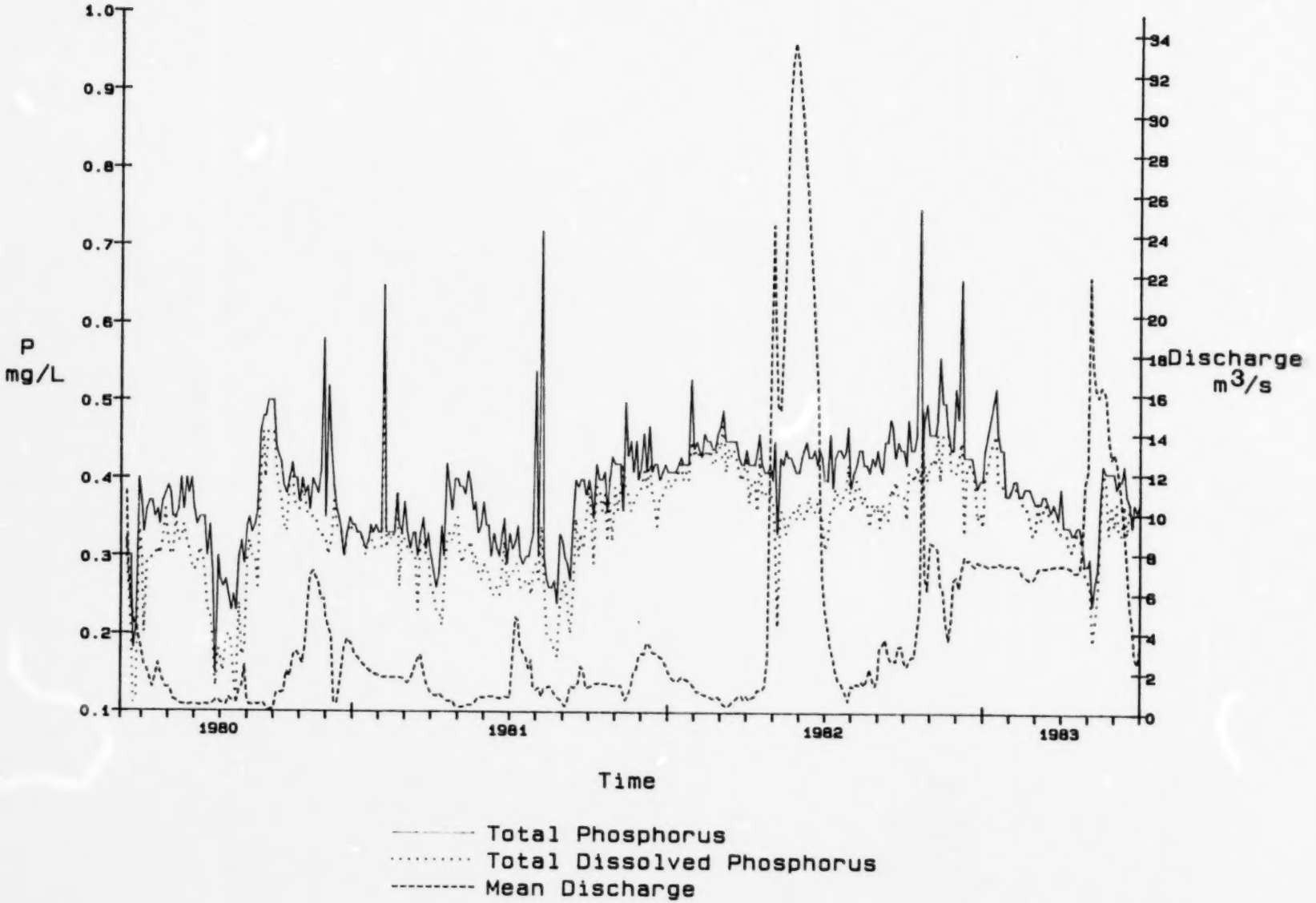

Figure 3. Mean Discharge and Phosphorus Concentration in the Qu'Appelle River Below Katepwa Lake.

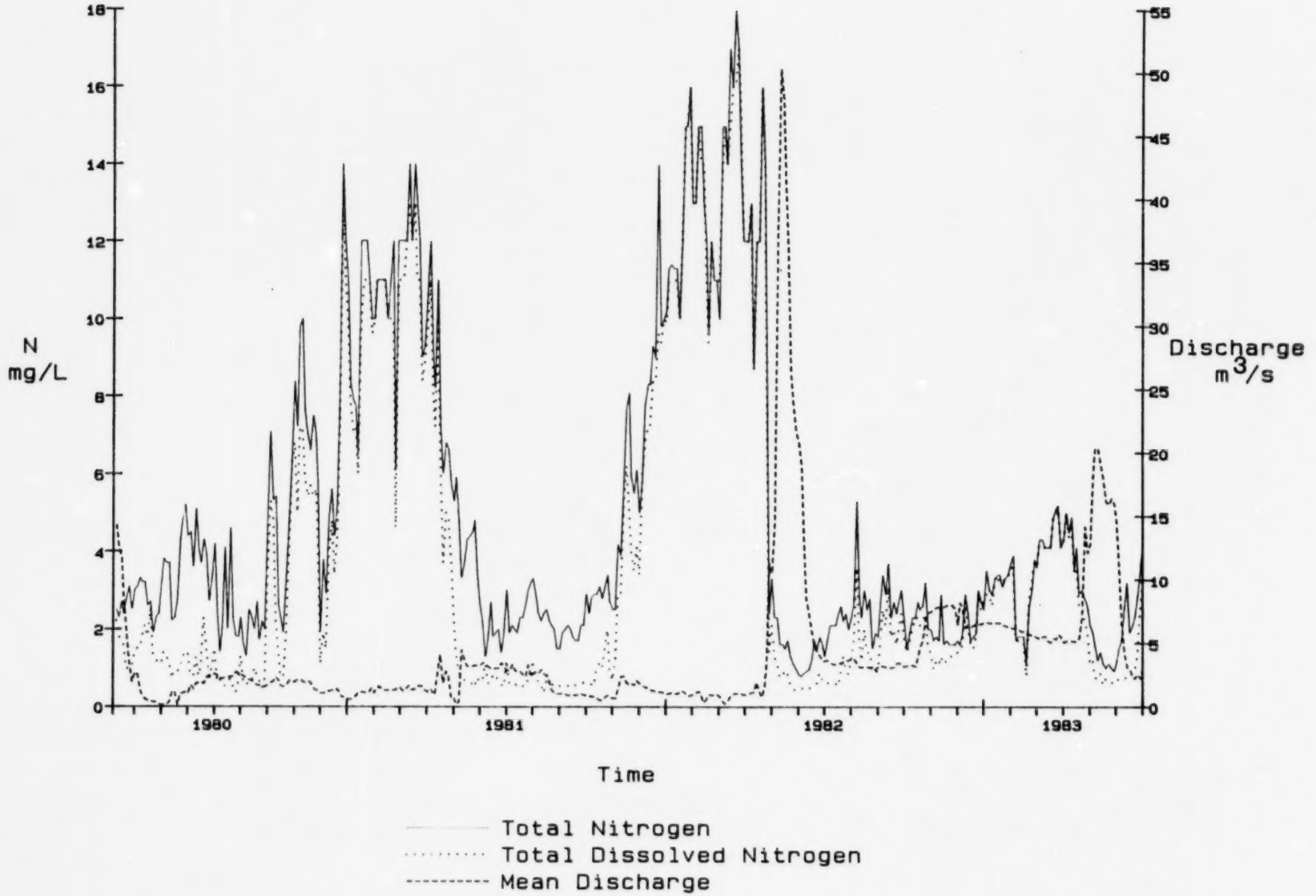

Figure 4. Mean Discharge and Nitrogen Concentration in the Qu'Appelle River Above Pasqua Lake.

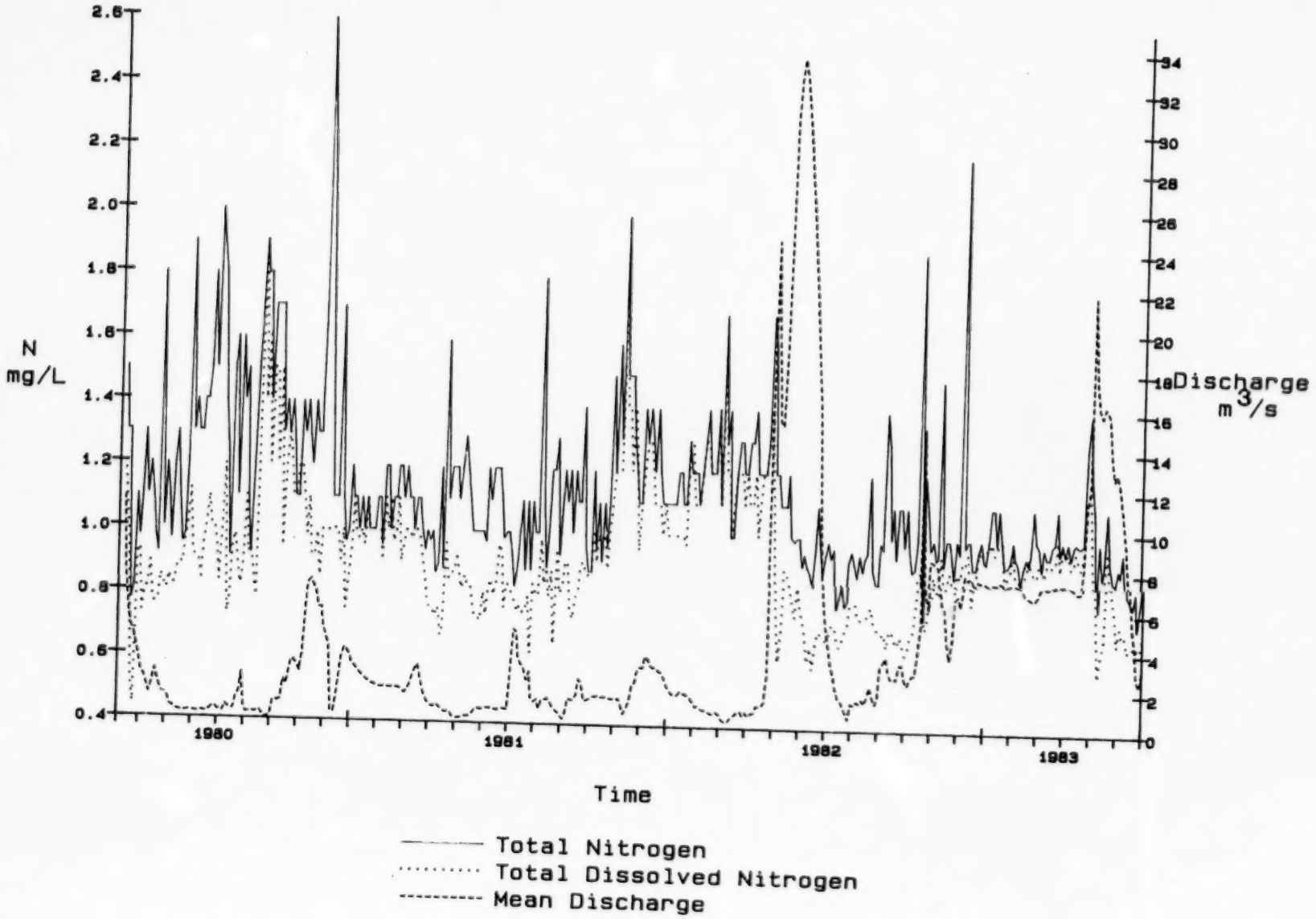

Figure 5. Mean Discharge and Nitrogen Concentration in the Qu'Appelle River Below Katepwa Lake.

residue, indicating that some disturbance upstream was probably responsible for the short duration increase in phosphorus. Phosphorus concentrations tended to be higher during the winter months in this period of the study. This period of wide variation in phosphorus concentration ended during the high spring flow in 1982. At that time the phosphorus concentration declined from a winter high of approximately 1.0 mg/L to less than 0.3 mg/L, and basically remained at or below 0.3 mg/L until near the end of the study, at which point the concentration of phosphorus increased to as high as 0.70 mg/L. This period of lower phosphorus concentration may be the result of flushing of nutrients during high flow. During the open water periods, at the site above Pasqua Lake, particulate phosphorus made up the major portion of the total phosphorus, in contract to the winter when the major portion was dissolved phosphorus. The higher proportion of particulate phosphorus in the open water periods was probably due to higher soil erosion inputting phosphorus into the water and to the uptake of dissolved phosphorus by biological organisms. During the winter months soil erosion would be greatly reduced, while senescense of plants and algae in the river in combination with reduced biological uptake would cause an increase in dissolved phosphorus into the water.

At the sampling site below Katepwa Lake the phosphorus concentration varied within a much narrower range (Figure 3) than above the Fishing Lakes. Typically the phosphorus ranged from 0.2 to 0.5 mg/L with only the occasional sample having concentrations outside that range. During the first 18 months of the study, the phosphosus concentration varied with time. In July, 1980 the concentration was depressed, and in September, 1980 the concentration increased significantly. It is believed these shifts were due to the influence of the algal populations in the lakes depleting the phosphorus during a bloom, and then releasing it once again during senescence. During the second half of the study the phosphorus concentration was relatively constant, but at a higher level than in the earlier part of the study. In September of 1981 the level increased and remained elevated (greater than 0.4 mg/L) until the spring of 1983. Throughout the study the major portion of the total phosphorus at the location below Katepwa Lake was dissolved phosphorus. The stabilizing influence of the lakes was no doubt responsible for the lower variability in phosphorus concentrations at the Katepwa site and the fact the the majority of the phosphorus was in the dissolved form.

5.2.2 Nitrogen

Nitrogen concentrations at the site above Pasqua Lake (Figure 4) followed two different annual patterns. During the first two years of the study, total nitrogen levels were low in the open water months, ranging between 2.0 and 5.0 mg/L, then increasing rapidly to levels usually greater than 10. mg/L during the winter. During the high spring flow in 1982 the nitrogen levels declined to less then 3.0 mg/L and did not

increase significantly during the remainder of the study. Thus the winter of 1982-83 did not reflect the high concentrations seen in previous winters. As with phosphorus at this location, particulate nitrogen made up the majority of the total nitrogen during the open water periods and dissolved forms were most significant during the winter months, no doubt for reasons similar to those suggested for phosphorus.

At the collection site below Katepwa Lake the nitrogen concentration was quite constant throughout the study, remaining within the range of 0.8 to 2.0 mg/L. This is considerably lower than the levels found in the upstream samples. The major components of the total nitrogen at the site below the lakes were the dissolved forms (69 percent).

5.3 Nutrient Loading

5.3.1 Phosphorus Loading

Phosphorus loading to and from the Fishing Lakes varied considerably over time, reflecting the variation in phosphorus concentration and flow. Monthly phosphorus load calculations for the two sampling sites are shown graphically in Figures 6 and 7. At the site above Pasqua Lake the monthly phosphorus load ranged from 0.56 tonnes in February, 1982 to 17.89 tonnes in April, 1982. Below Katepwa Lake the monthly loads ranged from 0.32 tonnes in July, 1980 to 34.13 tonnes in May, 1982. Typically, the greatest monthly loads occurred during spring runoff. The exception to this is the spring of 1981 at the site below Katepwa Lake when the phosphorus load was only 0.43 and 0.50 tonnes for April and May, respectively. These low spring loads reflect the very low spring flow in 1981. The most significant monthly phosphorus loads at both sites occurred during the spring of 1982, the highest flow period during the study. Over the study period, spring high flow months (April and May) contributed 46 and 44 percent of the total phosphorus load at the upstream and downstream sites, respectively. At the downstream site this corresponds very well with the percentage of the total discharge which occurred during these months. At the site above Pasqua Lake, however, the 46 percent of the total phosphorus load is considerably less than the 58 percent of the total discharge which occurred in the same months. This discrepancy may be a reflection of the continuous input of phosphorus into the system from point sources, such as the Regina and Moose Jaw sewage effluent, which produce a relatively constant phosphorus load throughout the year regardless of the flow.

Annual phosphorus loads (Table 2) during 1980 and 1981 at the two sites were in the order of 20 tonnes with input somewhat greater than output, resulting in a net influx of phosphorus into the Fishing Lakes of 10.63 tonnes. In 1982 the output of phosphorus from the lakes greatly exceeded the input resulting in a net output of 34.42 tonnes. During the first six months of

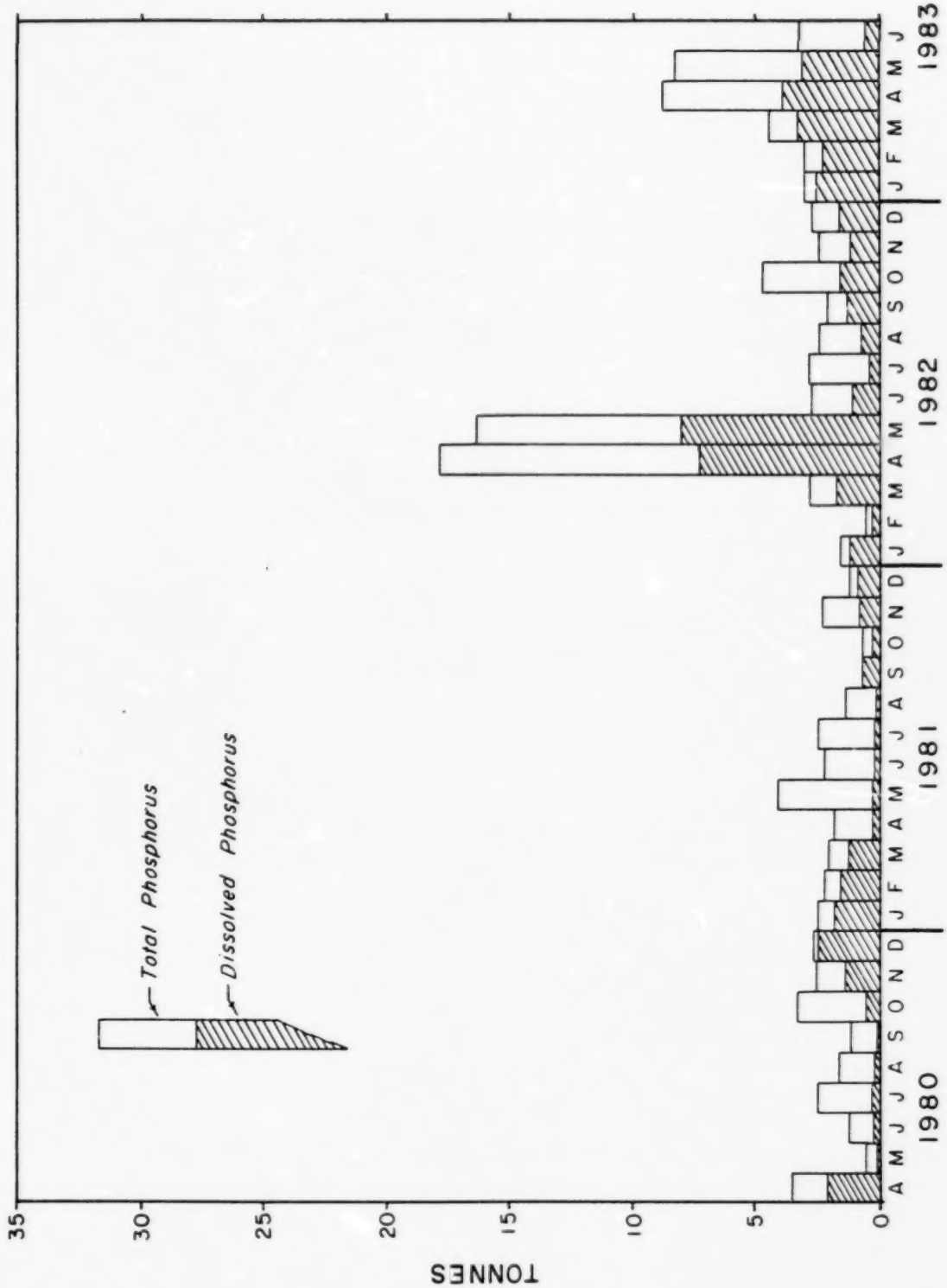

Figure 6 Monthly Phosphorus Load in the Qu'Appelle River Above Pasqua Lake, 1980 to 1983.

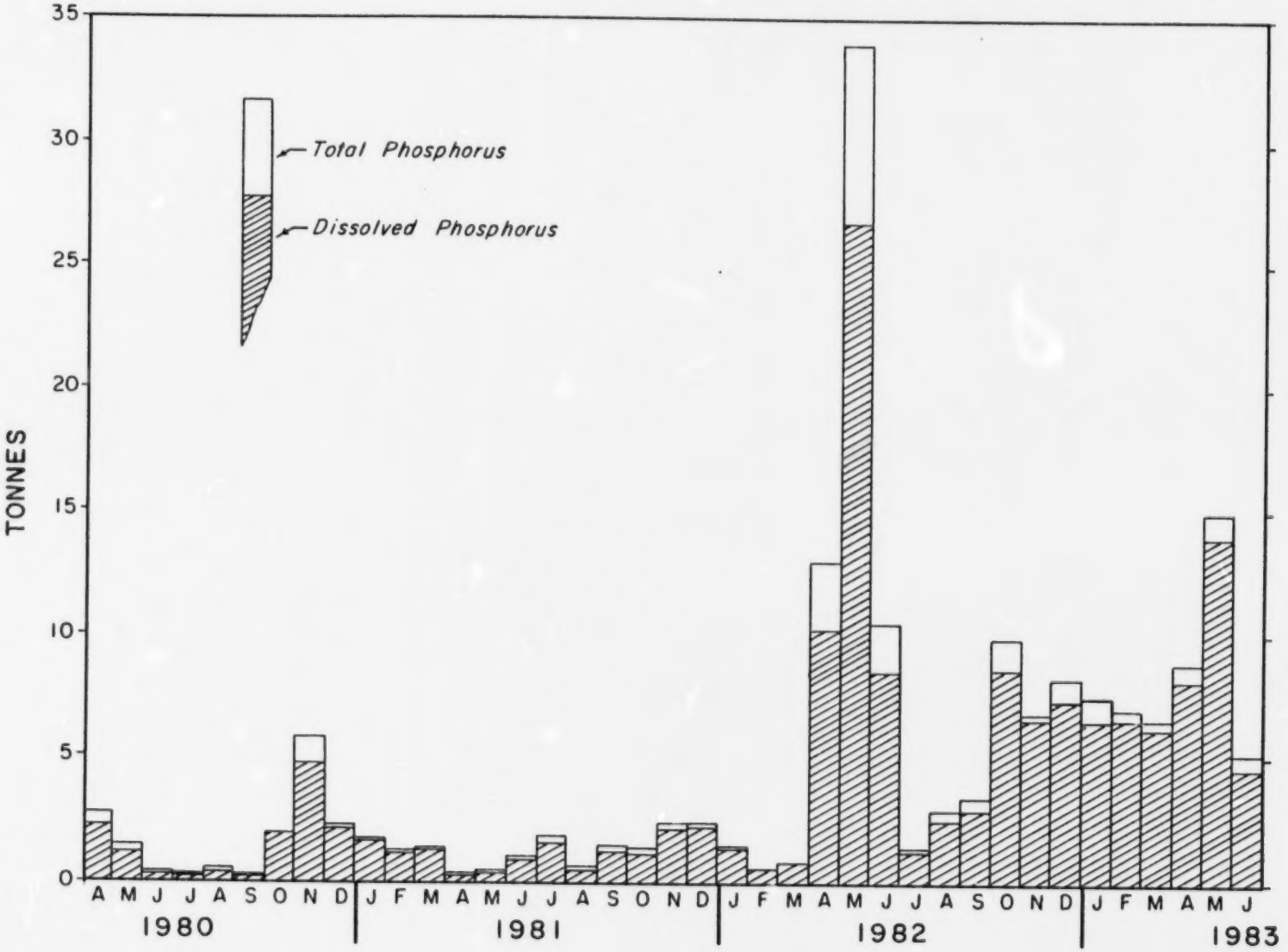

Figure 7 Monthly Phosphorus Load in the Qu'Appelle River Below Katepwa Lake, 1980 to 1983.

Table 2. Total Annual Nutrient Load To and From the Fishing Lakes (Tonnes).

Period	Nutrient	To the Lakes	From the Lakes
April to December, 1980	Total Phosphorus	19.76+/- 0.16	16.50+/- 0.23
	Dissolved Phosphorus	8.05+/- 0.79	13.85+/- 0.16
	Total Nitrogen	175.29+/-12.30	64.72+/- 4.04
	Dissolved Nitrogen	111.29+/- 3.92	44.49+/- 2.11
January to December, 1981	Total Phosphorus	24.45+/- 0.24	17.03+/- 0.26
	Dissolved Phosphorus	8.42+/- 0.13	15.20+/- 0.18
	Total Nitrogen	291.59+/- 6.83	50.54+/- 1.29
	Dissolved Nitrogen	202.20+/- 2.98	44.02+/- 0.60
January to December, 1982	Total Phosphorus	59.66+/- 1.01	94.08+/- 0.98
	Dissolved Phosphorus	26.89+/- 0.04	78.47+/- 2.03
	Total Nitrogen	469.90+/- 5.68	213.0 +/- 3.41
	Dissolved Nitrogen	342.40+/- 3.00	172.70+/- 2.68
January to June, 1983	Total Phosphorus	31.23+/- 0.54	50.68+/- 0.59
	Dissolved Phosphorus	15.77+/- 0.38	46.61+/- 0.65
	Total Nitrogen	307.58+/- 6.41	138.90+/- 2.22
	Dissolved Nitrogen	173.21+/- 4.26	61.29+/- 0.83
April, 1980 to June, 1983	Total Phosphorus	135.10+/- 0.54	178.29+/- 2.06
	Dissolved Phosphorus	59.13+/- 0.38	154.13+/- 3.02
	Total Nitrogen	1244.36+/-31.22	467.16+/-10.96
	Dissolved Nitrogen	829.10+/-14.16	322.60+/- 6.22

1983 there continued to be a net output of phosphorus from the lakes (19.43 tonnes). Thus, over the 39 months of intensive sampling there was a net output of phosphorus from the Fishing Lakes of 43.19 tonnes.

5.3.2 Nitrogen Loading

The monthly nitrogen loads into and out of the Fishing Lakes are shown in Figures 8 and 9. Above Pasqua Lake the monthly nitrogen load ranged from 4.99 tonnes in September, 1981 to 105.5 tonnes in April, 1982. Below Katepwa Lake the monthly nitrogen load ranged from 1.31 tonnes in June, 1980 and April, 1981 to 75.73 tonnes in May, 1982. Monthly nitrogen loads were substantially lower at the site below Katepwa Lake than at the upstream site throughout the entire study.

At the site below Katepwa Lake the monthly nitrogen loads were proportional to the flow throughout the study. At the site above Pasqua Lake nitrogen loads were not proportional to the flow. During the high spring flow months (April and May), 58 percent of the total discharge for the study period occurred, while only 33 percent of the nitrogen load occurred during the same periods. In the winter months 48 percent of the nitrogen load occurred, compared with only 26 percent of the total discharge. This disproportional relationship between nitrogen load and flow can probably be explained by the greater proportion of nitrogen-rich ground water in the river, the continuous input of nitrogen from point sources and the decrease in biological activity during the winter.

The nitrogen load into the Fishing Lakes over the study period (Table 2) was 1244.4 tonnes, of which 829.1 tonnes was dissolved nitrogen. The largest annual load (470 tonnes) occurred in 1982. At the site below Katepwa Lake the total nitrogen load over the study was 467.2 tonnes, of which 322.6 tonnes was dissolved nitrogen. Subtraction of the loads into and out of the lakes shows there was a net nitrogen influx of 777.2 tonnes from April, 1980 to June, 1983.

5.4 Phosphorus Speciation

Fourteen samples were collected for phosphorus speciation analysis at each site during the study. The results of the speciation analyses are summarized in Table 3. The results show a significant difference in the concentrations of the phosphorus forms found above and below the Fishing Lakes.

Above Pasqua Lake the forms of phosphorus varied with the season. During the open water seasons the majority of the phosphoruswas in a particulate form (mean 75 percent) and only a small portionof the dissolved phosphorus (mean 30 percent) was ortho-phosphorus. In the winter, under the ice, the proportion of particulate phosphorus was signficantly lower (mean 27

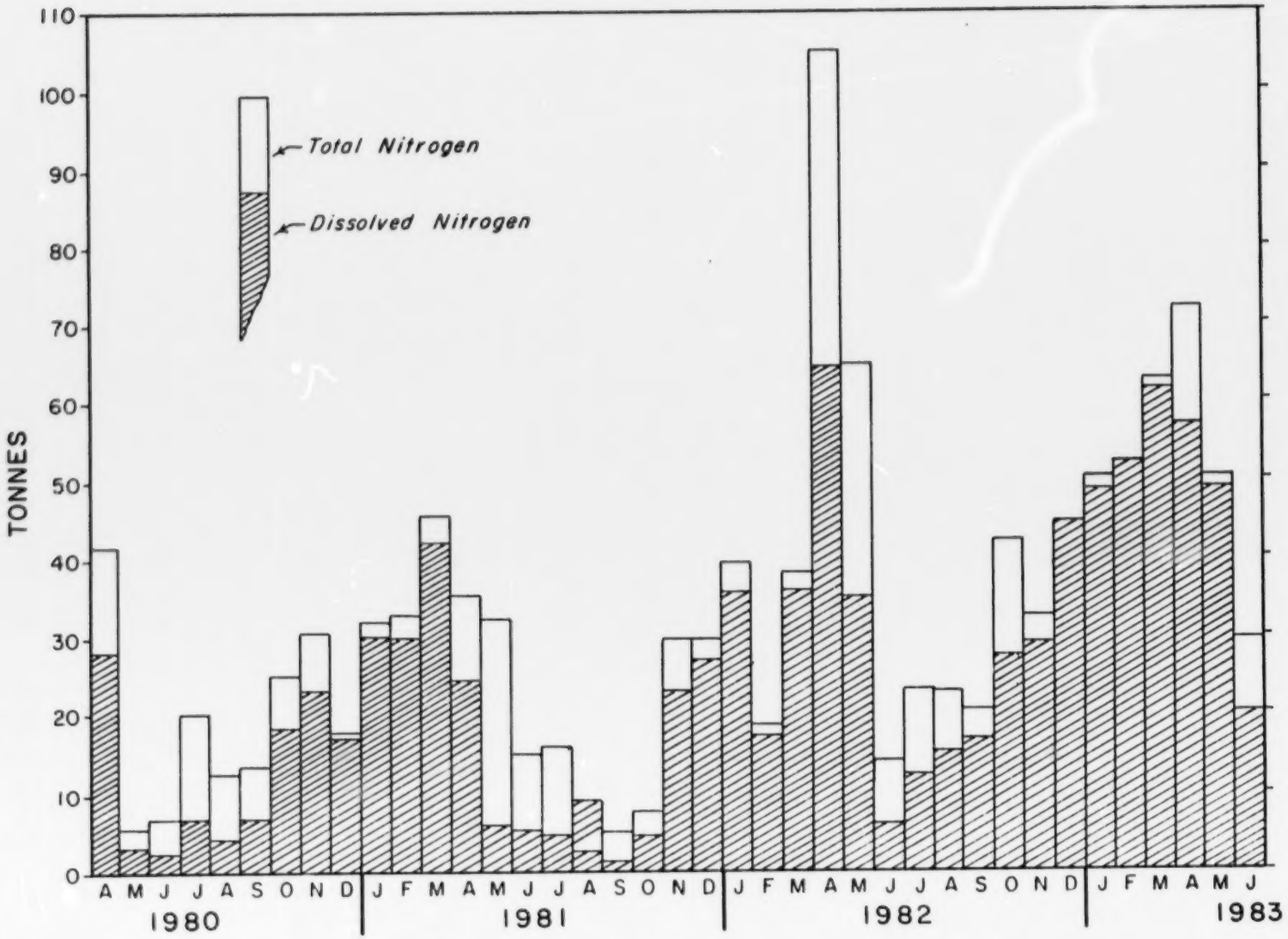

Figure 8 Monthly Nitrogen Load in the Qu'Appelle River Above Pasqua Lake, 1980 to 1983.

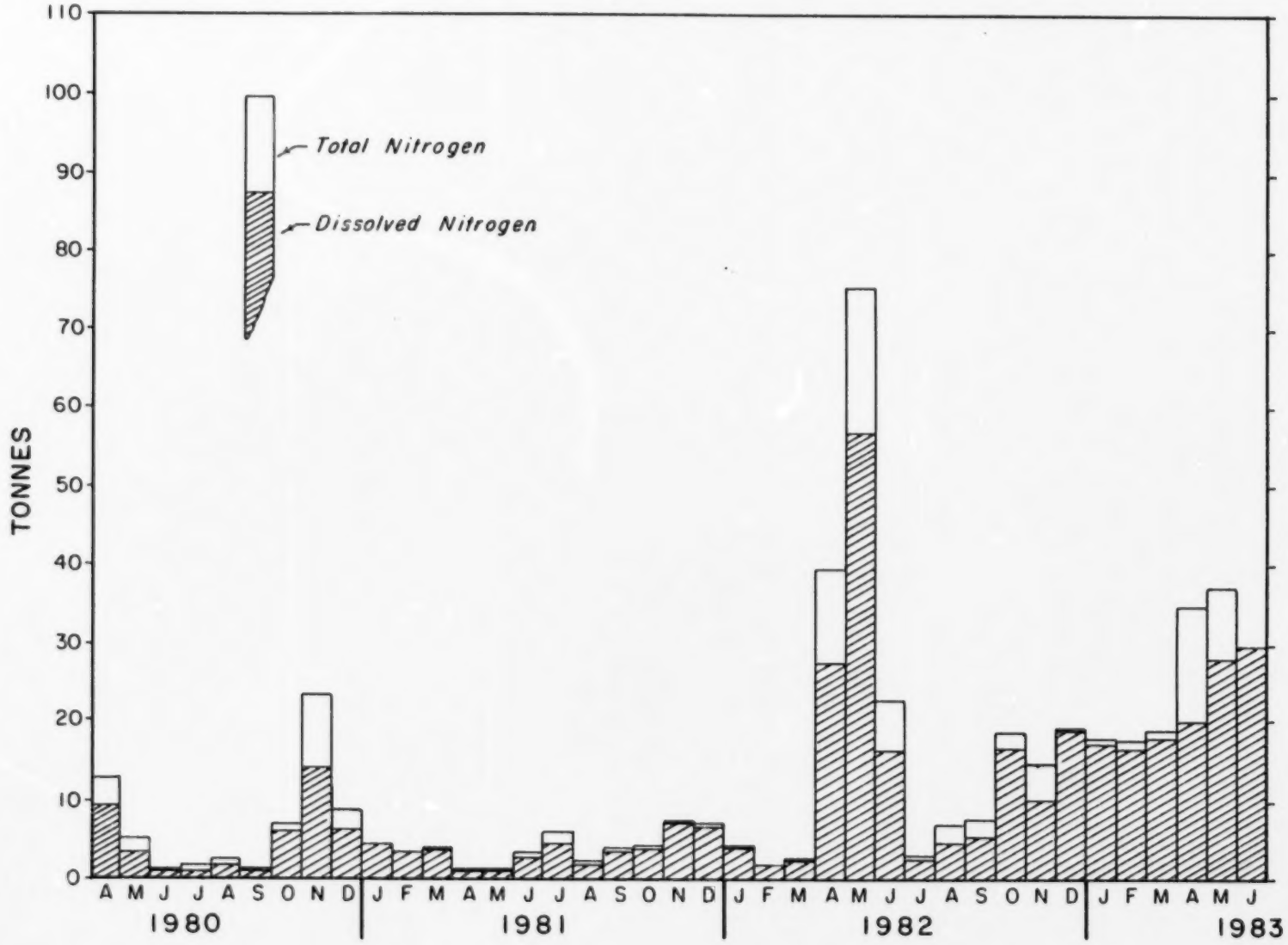

Figure 9 Monthly Nitrogen Load in the Qu'Appelle River Below Katepwa Lake, 1980 to 1983.

Table 3. Phosphorus Species in the Qu'Appelle River.

Date Sampled	TP (mg/L)	DP (mg/L)	DOP (mg/L)	TIP (mg/L)	DIP (mg/L)
Above Pasqua Lake					
5-MAY-80	0.60	0.120	0.044	0.460	0.062
16-JUL-80	0.42	0.051	L0.003	0.023	0.021
8-SEP-80	0.25	0.020	L0.003	0.140	0.005
7-JAN-82	0.54	0.450	0.390	0.500	0.420
15-FEB-82	0.34	0.260	0.220	0.310	0.240
25-APR-82	0.29	0.087	0.060	0.200	0.061
3-JUN-82	0.27	0.060	0.020	0.220	0.042
6-JUL-82	0.30	0.018	L0.003	0.230	0.007
7-SEP-82	0.21	0.110	0.045	0.180	0.054
10-OCT-82	0.26	0.150	0.091	0.220	0.120
31-OCT-82	0.16	0.063	0.032	0.110	0.040
14-JAN-83	0.17	0.110	0.060	0.160	0.091
19-FEB-83	0.25	0.170	0.160	0.230	0.170
14-APR-83	0.27	0.100	0.013	0.230	0.048
Below Katepwa Lake					
8-MAY-80	0.34	0.300	0.250	0.320	0.250
19-JUL-80	0.27	0.190	0.120	0.150	0.140
14-SEP-80	0.50	0.480	0.420	0.470	0.420
10-JAN-83	0.43	0.420	0.380	0.410	0.390
18-FEB-82	0.49	0.460	0.420	0.450	0.440
1-MAY-82	0.42	0.360	0.350	0.400	0.350
31-MAY-82	0.43	0.380	0.330	0.380	0.350
30-JUN-82	0.43	0.400	0.360	0.420	0.370
4-SEP-82	0.45	0.370	0.310	0.360	0.340
28-SEP-82	0.46	0.420	0.400	0.430	0.420
6-NOV-82	0.47	0.440	0.410	0.420	0.410
18-NOV-82	0.50	0.430	0.410	0.420	0.410
24-NOV-83	0.43	0.420	0.410	0.410	0.410
11-APR-83	0.32	0.320	0.260	0.280	0.270

Phosphorus forms: TP = total, DP = total dissolved, DOP = dissolved ortho, TIP = total inorganic, DIP = dissolved inorganic

percent) than during open water periods and the proportion of total phosphorus represented by dissolved phosphorus and ortho-phosphorus approached those found at the site below Katepwa Lake. Dissolved inorganic phosphorus in the winter samples was for the most part ortho-phosphorus unlike samples from the open water periods.

At the site below Katepwa Lake the phosphorus was for the most part in a dissolved form (greater than 80 percent) with ortho-phosphorus representing the majority of that dissolved phosphorus (greater than 80 percent). The exception to this was the sample collected in July, 1980 when 70 percent of the phosphorus was dissolved and only 63 percent of that was ortho-phosphorus.

No attempt was made during this study to determine biologically what amount of the various forms of phosphorus were actually biologically available or to what extent.

6.0 DISCUSSION

6.1 Phosphorus

A reliable phosphorus budget for the Fishing Lakes during the study period can not be done as all the sources of phosphorus were not monitored. However, based upon the estimates of river borne phosphorus into and out of the Fishing Lakes, there was a flushing of 43.19 tonnes of phosphorus from the lakes during this 39 month study.

Pasqua Lake, because it is the first in the chain of Fishing Lakes, is likely the primary settling basin for river borne suspended particulate matter. During the study period 85.97 tonnes of particulate phosphorus were transported into the Fishing Lakes and only 24.16 tonnes exported to the lower Qu'Appelle River, suggesting that 61.81 tonnes of particulate phosphorus may have been retained in the Fishing Lakes. To what extent suspended particulate phosphorus was converted chemically or biologically to dissolved phosphorus within the lake system is unknown. However, it is a reasonable assumption that a significant portion of the particulate phosphorus was deposited in the Fishing Lakes with the suspended sediment.

If it is assumed that the difference in particulate phosphorus load into and out of the lakes is the result of settling, then there must be a large source or sources of phosphorus within the local catchment area which would have to account for not just the net exported amount (43.19 tonnes) but also the net desposited particulate phosphorus (61.81 tonnes). This represents a total of 105 tonnes potentially derived from sources other than the inflow from the Qu'Appelle River. Contrasting this amount to the inflow of 135 tonnes, emphasizes the importance of the unknown variables in the budget equation. A number of possible sources or causes for this 105 tonnes of

phosphorus exist, including: the effect of travel time between sites, phosphorus regeneration and release from the bottom sediment, local runoff, precipitation and groundwater inputs.

Travel time between the two sampling locations will have contributed to some of the difference in phosphorus load as obviously all the water that was sampled entering the lakes during the study did not leave the lakes. It is possible, although unlikely, that none of the water that entered Pasqua Lake during the study actually reached the outlet of Katepwa Lake, as there was insufficent flow at the site above Pasqua Lake to replace all the water in the four Fishing Lakes (431.4 dam^3 of discharge compared to a lake volume of 537.12 dam^3 (Allan and Kenny, 1978)). However, it is reasonable to assume that the nutrient levels in the Qu'Appelle River above Pasqua Lake did not vary to a great extent immediately prior to this study and that a portion of the water was actually sampled at both sites. Travel time cannot, therefore, account for all the difference.

Samples collected at the outlet of Pasqua Lake during November and December of 1981 (Water Quality Branch, unpublished data) show that the shift from particulate phosphorus to dissolved phosphorus had occurred by this point in the river system. Dissolved phosphorus represented more than 90 percent of the total phosphorus (mean = 0.49 mg/L) in 12 samples collected at three day intervals. This suggests that in-lake processes are likely responsible for the shift in phosphorus forms. Allan and Williams, (1978) reported that the bottom sediments in the Fishing Lakes are high in available phosphorus. They also reported the likelihood that bottom sediments may provide an ongoing source of available phosphorus to eutrophic lake waters supporting nuisance biological growths. This could explain the increased levels of dissolved phosphorus in the outflow waters from Katepwa Lake. Anoxic conditions, which are known to occur at the sediment-water interface in these lakes, are conducive to phosphorus mobilization into the water column (Lazoff, 1982; Stefan, et al., 1981). Rooted aquatic macrophytes can also act as agents of internal phosphorus loading from bottom sediments. This loading can be the result of the active pumping of nutrient from the sediments by the plants (Barko and Smart, 1980; Best and Barsdate, 1978; Carignan and Kalff, 1980) or from the dieback effect of senescing populations of macrophytes, resulting in the release of phosphorus which originated from the sediments (Landers, 1982). Whether or not the high dissolved phosphorus in the outflow water reflects actual processes having taken place within the lakes cannot be answered by this study and is open to discussion. The substantially higher dissolved phosphorus in the outflow than the inflow is presumptive evidence that internal regeneration of phosphorus is a major factor affecting the quality of the Fishing Lakes and the lower Qu'Appelle River. Therefore, phosphorus regeneration is an important variable in any ongoing management strategy focusing on phosphorus control and should be assessed.

As noted above, other sources of phosphorus not addressed in this study (e.g. local runoff, precipitation and groundwater) which could contribute to the high dissolved phosphorus in the outflow.

In the original design of this study, sources of phosphorus to the Fishing Lakes other than the Qu'Appelle River were assumed to be minimal relative to the Qu'Appelle River, and they were therefore not investigated. However, the large increase in dissolved phosphorus load out of the lake compared with the input show this was a poor assumption, as other sources of phosphorus contributed almost as much phosphorus as the Qu'Appelle River. These other source should have been examined in order to get a true understanding of phosphorus loading to the Fishing Lakes and of the significance of controlling point source input of nutrients.

Ortho-phosphorus, or soluble reactive phosphorus has been used to estimate the biologically available portion of the total phosphorus in water. The phosphorus speciation data showed that the water entering the lakes has only a small portion of ortho-phosphorus during the open water periods, ranging from less than 0.003 to 0.091 mg/L, suggesting that there is a limited amount of biologically available phosphorus entering Pasqua Lake. However, other dissolved inorganic forms of phosporus can also be available (Sonzogni, et al., 1982). In addition, it has been shown that dissolved organic phosphorus can also be utilized by algae, particularly when ortho-phosphorus levels are low (Kramer, et al., 1972). Ongley (1978) reports that a portion of the particulate phosphorus can be biologically available. Thus, there is probably more biologically available phosphorus entering the lakes than indicated by the ortho-phosphorus data. Within the Fishing Lakes there is a significant shift in the phosphorus forms present and the concentrations of ortho-phosphorus leaving Katepwa Lake are very high, ranging from 0.12 to 0.42 mg/L. These high concentrations of ortho-phosphorus represent a very large pool of biologically available phosphorus, not to mention the possibility that some of the other phosphorus forms present could also be available. Samples collected from the outlet of Pasqua Lake in November and December of 1981 showed that this high level of biologically available phosphorus probably exists through a portion of Pasqua Lake and throughout the three downstream lakes (Echo, Mission and Katepwa Lakes).

6.2 Nitrogen

Throughout the study the nitrogen concentration in the Qu'Appelle River entering the Fishing Lakes was higher than that leaving the lakes. This difference in concentration resulted in a significant input of nitrogen into the Fishing Lakes (777 tonnes). It is reasonable to assume that a large portion of the 375.26 tonnes of particulate nitrogen entering the Fishing Lakes would be deposited in the lake sediments of Pasqua Lake with the

settling of suspended sediment. Simple substraction of the particulate nitrogen load leaving the lakes from that entering the lakes suggest approximately 230 tonnes of the nitrogen input to the lakes was the result of deposition of particulate nitrogen. The remaining nitrogen input to the lakes can probably be attributed to the difference in the waters sampled due to travel time (as discussed in the previous section), to biological uptake and to denitrification.

The decrease in nitrogen concentrations between the inlet and the outlet waters of the Fishing Lakes results in a significant difference in the nitrogen to phosphorus ratios between the two sites. Over the entire study period the ratios of total nitrogen to total phosphorus were 9.2 to 1 at the upstream site and 2.6 to 1 at the downstream site. At the downstream site the ratio of nitrogen to phosphorus did not change much between seasons: at the site above Pasqua Lake the ratios did display substantial seasonal variation. The winter months had the highest nitrogen to phosphorus ratio, 15.2 to 1 compared to 6.6 to 1 and 7.6 to 1 in the spring and summer, respectively. A total nitrogen to total phosphorus ratio of 15 to 1 is generally considered to be the optimum ratio for algal growth (Rast and Lee, 1978) with lower ratios suggesting that nitrogen is limiting algal growth. This decrease in nitrogen relative to phosphorus, supports the theory presented by Allan and Kenny (1978) and Allan and Roy (1980) that nitrogen, rather than phosphorus may be limiting algal growth within the lakes. If nitrogen is, in fact, limiting algal growth in the Fishing Lakes, the control of phosphorus inputs to the lakes would have much less effect on productivity than if phosphorus were limiting.

Control of nitrogen is much more difficult than phosphorus because the atmosphere represents a major source of nitrogen over which man has virtually no control. The fixation of atmospheric nitrogen by bacteria and algae has been shown to represent from less than one precent to as much as 50 percent of the total nitrogen inflow into lakes (Ashton, 1979, 1981; Tilson, et al., 1977; Horne, 1979) depending on various factors, including organisms present, water temperature, whether the system is nitrogen limiting and the trophic state of the lake. The significance of sources of nitrogen to the Fishing Lakes other than the Qu'Appelle River connot be assessed with the data from this study, but the low nitrogen to phosphorus ratios suggest that nitrogen fixation may be occurring and acting as a major source of nitrogen.

Management strategies througout Canada justifiably focus on controlling point source pollution. Phosphorus is a contributing factor to eutrophication, and hence, reductions in phosphorus loadings from municipal, industrial and agricultural point sources are desirable to protect recreational, domestic and drinking water uses. However, it is becoming more apparent that controlling eutrophication through phosphorus control is only an important first step. Controlling eutrophication in

systems like the Fishing Lakes may require other progressive measures such as modification of land use practices, lake level regulations, lake reclamation and nitrogen control.

6.3 Assessment of Sampling Frequency

During this study the frequency of sampling was very high. This high frequency of sampling was necessary to assure as accurate a load calculation as possible. However, the cost of this sampling was high both in terms of dollars and human resources. Therefore, the frequency of sampling required to obtain phosphorus loads into the Fishing Lake with acceptable accuracy was examined.

Phosphorus loads were calculated based on the phosphorus data taken at fixed intervals and the discharge over the time interval between sample dates. The fixed intervals included every third, fifth and tenth sample to approximate weekly, biweekly and monthly sample collection. Phosphorus loads were calculated for all the possible combinations which maintained the fixed interval, resulting in three weekly, five biweekly and ten monthly loads for each time period examined. Four time periods were examined: the entire period of intensive sampling, spring high flow (periods with flow greater than 8.0 m /s), summer (periods of open water when the flow was less than 8.0 m /s), and winter (periods of ice cover). Table 4 summarizes the results of these load calculations. It should be noted that the loads calculated in this exercise are slightly different from the intensive sampling because the phosphorus data were not corrected for cross sectional heterogeneity. As would be expected, the accuracy of the load calculation decreased as the sampling frequency was reduced, except during the summer period when the accuracy was basically the same at all three sampling frequencies.

In order to use these calculations to address the question of how often samples should be collected, an acceptable error must be established. If a ten percent error is considered acceptable, weekly sampling would be required to establish seasonal loads at the upstream site, while biweekly would suffice at the downstream site. Annual loads could determined with the same error from biweekly and monthly sampling at the upstream and downstream sites, respectively.

Table 4. Phosphorus Load Calculations Based on Various Sampling Periods for the Qu'Appelle River above Pasqua Lake.

Sample Period/ Frequency	Number of Calculations	Mean Load	Standard Deviation	Coefficent of Variation (%)	Maximun Load	Minimun Load
Entire Period/						
All samples	1	133.06				
Monthly	10	137.87	12.21	8.8	154.84	122.01
Biweekly	5	136.13	4.41	3.3	141.69	132.49
Weekly	3	133.85	1.82	1.4	135.82	132.23
Spring/						
All Samples	1	50.06				
Weekly	3	50.69	2.04	4.0	52.27	48.35
Summer/						
All Samples	1	46.68				
Monthly	10	47.12	5.02	10.7	58.12	40.36
Biweekly	5	47.16	4.90	10.4	55.05	42.94
Weekly	3	46.42	5.20	11.2	52.27	42.29
Winter/						
All Samples	1	36.32				
Monthly	10	36.31	5.30	14.6	45.78	30.81
Biweekly	5	37.37	2.77	7.4	39.98	33.33
Weekly	3	35.70	1.23	3.4	36.98	34.52

Table 5. Phosphorus Load Calculations Based on Various Sampling Periods for the Qu'Appelle River below Katepwa Lake

Sample Period/ Frequency	Number of Calculations	Mean Load	Standard Deviation	Coefficent of Variation (%)	Maximun Load	Minimun Load
Entire Period/						
All samples	1	177.33				
Monthly	10	179.30	3.42	1.9	187.55	176.19
Biweekly	5	176.43	2.80	1.6	181.03	173.93
Weekly	3	176.44	0.92	0.5	177.18	175.40
Spring/						
All Samples	1	77.74				
Monthly	10	71.43	4.32	6.1	77.41	63.76
Biweekly	5	74.87	2.34	3.1	77.46	71.48
Weekly	3	76.01	0.63	0.8	76.70	75.45
Summer/						
All Samples	1	38.12				
Monthly	10	42.86	4.66	10.9	50.28	37.19
Biweekly	5	38.72	3.79	9.8	42.85	34.64
Weekly	3	38.43	2.28	5.9	40.22	35.37
Winter/						
All Samples	1	61.44				
Monthly	10	64.97	7.69	11.8	77.60	56.09
Biweekly	5	62.66	3.34	5.3	67.72	59.51
Weekly	3	61.96	1.48	2.3	63.64	60.83

ACKNOWLEDGEMENTS

The author wishs to thank the staff of the Water Quality Branch Laboratory Western and Northern Region for conducting the chemical analyses. The assistance received from the staff of the Water Resources Branch in Regina, both in terms of providing flow data on a timely basis throughout the study and in interpreting some of the data was appreciated. In addition I would like to thank D. Gregor, H. Vaughan and Wm Gummer for their advice and assistance in writing and reviewing this report.

REFERENCES

Allan, R.J., 1980. The Inadequacy of Existing Chlorophyll a / Phosphorus Concentration correlations for Assessing Remedial Measures for Hypertrophic Lakes. Environmental Pollution (Series B) Vol. 1 pp. 217-231.

Allan, R.J. and B.C. Kenny, 1978. Rehabilitation of Eutrophic Prairie Lakes in Canada. Verh. Int. Ver. Limnol. Vol. 20 pp. 214-224.

Allan, R.J. and M. Roy, 1980. Lake Water Nutrient Chemistry and Chlorophyll a in Pasqua, Echo, Mission, Katepwa, Crooked and Round Lakes on the Qu'Appelle River, Saskatchewan. Enbvironment Canada, National Water Research Institute, Inland Waters Directorate, Regina, Saskatchewan. Scientific Series No. 12.

Allan, R.J. and J.D.H. Williams, 1978. Trophic Status Related to Sediment Chemistry of Canadian Prairie Lakes. J. Environmental Quality Vol. 7 pp. 99-106.

Allan, R.J., J.D.H. Williams, S.R. Joshi and W.F. Warwick, 1980. Historical Changes and Relationship to Internal Loading of Sediment Phosphorus Forms in Hypertrophic Prairie Lakes. J. Environmental Quality Vol. 9 pp. 199-206.

Ashton, P.J., 1979. Nitrogen Fixation in a Nitrogen Limited Impoundment. J. Water Pollution Control Federation, Vol. 51 pp. 570-579.

Ashton, P.J., 1981. Nitrogen Fixation and the Nitrogen Budget of a Eutrophic Impoundment. Water Research Vol. 15 pp. 823-833.

ARDA, 1980. Agricultural and Rural Development Act, Soil Capability for Agriculture, Regina - 721, Canada Land Inventory, Ottawa.

Barko, J.W. and R.M. Smart, 1980. Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes. Freshwater Biology Vol. 10 pp. 229-238.

Best, M.D. and K.M. Mantai, 1978. Growth of Myriophyllum: Sediment or Lake Water as a Source of Nitrogen and Phosphorus. Ecology Vol. 59 pp. 1075-1080.

Carignan, R. and J. Kalff, 1980. Phosphorus Sources for Aquatic Weeds: Water or Sediment? Science Vol. 207 pp. 987-989.

Horne, A.J., 1979. Nitrogen Fixation in Clear Lake California 4. Diel Studies on Aphanizamenon and Anabaena blooms. Limnology and Oceanography Vol. 24 pp. 329-341.

House, R.H., 1981a. 1980 Station Analysis for Qu'Appelle River below Loon Creek. Water Resources Branch, Environment Canada, Regina.

House, R.H., 1981b. 1980 Station Analysis for Qu'Appelle River below Katepwa Lake. Water Resources Branch, Environment Canada, Regina.

Kramer J.R., S.E. Herbes and H.E. Allen, 1972. Phosphorus: Analysis of Water, Biomass and Sediment. In Nutrients in Natural Waters edited by H.E. Allen and J.R. Kramer. John Wiley and Son Ltd., Toronto.

Landers, D.H., 1982. Effects of Naturally Senescing Aquatic Macrophytes on Nutrient Chemistry and Chlorophyll-a of Surrounding Waters. Limnology and Oceanography Vol. 27 pp. 428-429.

Lazoff, S.V., 1983. Evaluation of Internal Phosphorus Loading from Anerobic Sediments. From the Proceeding of the Second Annual Conference of the North American Lake Management Society, Vancouver, B.C., 1982. U.S. Environmental Protection Agency, Washington, D.C. 1983.

Munro, D.J., 1986. Phosphorus Loading in the Qu'Appelle River, 1971 to 1983. Environment Canada, Water Quality Branch, Regina, Saskatchewan, WQB-WNR-86-03.

Ongley, E.D., 1978. Sediment-related Phosphorus, Trace Metals and Anion Flux in Two Rural Southeastern Ontario Catchments. Inland Water Directorate Research Subventions Probram Progress Report, Unpub. Ms.

Prairie Farm Rehabilitation Administration, 1980. Report on Determination of River Distances in the Saskatchewan - Nelson River Basin. Hydrology Report # 95, Regina, Saskatchewan.

Qu'Appelle Basin Study Board, 1972. Report of the Qu'Appelle Basin Study Board. Canada-Saskatchewan-Manitoba, Regina, Saskatchewan.

Rast, W. and G.F. Lee, 1978. Summary Analysis of the North American (US Portion) OECD Eutrophication Project: Nutrient Loading - Lake Response Relationships and Trophic State Indices. US Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development, Corvallis, Oregon. EPA-600/3-78-008.

Reid, K.W., 1979. Letter To Mr. D. Fast 'Water Quality Monitoring Required for Evaluating the Qu'Appelle Implementation Program'. Water Quality Branch, Environment Canada, Regina.

Reid Crowther / DPA Consortium, 1984. Canada / Saskatchewan Qu'Appelle Agreement Evaluation. Prepared for the Qu'Appelle Evaluation Committee.

Shoemaker, D.P., C.W. Garland and J.I. Steinfeld, 1974. Experiments in Physical Chemistry, Third Edition. McGraw-Hill Book Company.

Sonzogni, W.C., S.C. Chapra, D.E. Armstrong and T.J. Logan, 1982. Bioavailability of Phosphorus Inputs to Lakes. J. Environmental Quality Vol. 11 pp. 555-563.

Stefan, H.G., M. ASCE and M.J. Hanson, 1981. Phosphorus Recycling in Five Shallow Lakes. J. Environmental Engineering Division, Proceedings of the America Society of Civil Engineers, Vol. 107, EE4, pp. 713-730.

Tilson, D.L., F.E. Palmer and J.T. Staley, 1977. Nitrogen Fixation in Lakes of the Lake Washington Drainage Basin. Water Research Vol. 11 pp. 843-847.

Water Quality Branch, 1979. Analytical Methods Manual. Inland Waters Directorate, Environment Canada, Ottawa.

Water Quality Branch, 1982a. Qu'Appelle Fishing Lakes Nutrient Loading Study, 1980. Report No. 1 (Interim). Environment Canada, Water Quality Branch, Regina, Saskatchewan, WQB-WNR-82-02.

Water Quality Branch, 1982b. Qu'Appelle Fishing Lakes Nutrient Loading Study, 1981. Report No. 2 (Interim). Environment Canada, Water Quality Branch, Regina, Saskatchewan, WQB-WNR-82-01.

Water Quality Branch, 1983. Qu'Appelle Fishing Lakes Nutrient Loading Study, 1982. Report No. 3 (Interim). Environment Canada, Water Quality Branch, Regina, Saskatchewan, WQB-WNR-83-02.

Water Survey of Canada, 1980. Historical Streamflow Summary Saskatchewan, 1979. Inland Waters Directorate, Environment Canada, Ottawa.

Water Survey of Canada, 1981. Surface Water Data Saskatchewan, 1980. Inland Waters Directorate, Environment Canada, Ottawa.

Water Survey of Canada. 1982. Surface Water Data Saskatchewan. 1981. Inland Waters Directorate. Environment Canada. Ottawa.

Water Survey of Canada. 1983. Surface Water Data Saskatchewan. 1982. Inland Waters Directorate. Environment Canada. Ottawa.